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(58) Field of search
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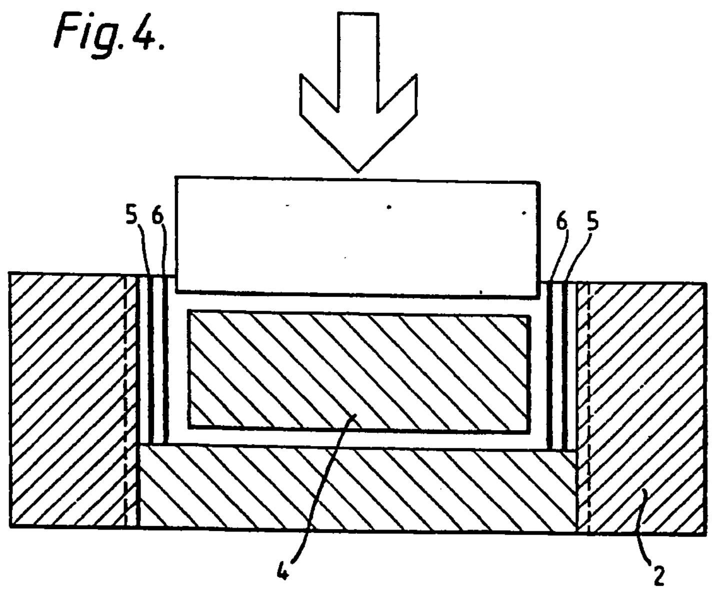
(54) Hard-surface composite parts

(57) A composite machinery part, desirable as it allows the properties of dissimilar metals to be utilised, is formed from two parts, one of hardenable steel 2 and another of a non-ferrous metal part 4. One part encircles an interprojecting portion of the other, the steel part having keying recesses or projections circumferential, axial or helical and the non-ferrous part is plastically deformed to intimately contact and key with the steel part. A diffusion bond is formed at the joint.

Such a composite part is suitable for use as a gear having a load bearing portion of hard wearing steel and another portion of a lightweight alloy of aluminium, nickel or titanium. Preferably the composite part is so configured that the joint is at all times under compression.

Fig. 4.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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Fig. 1.

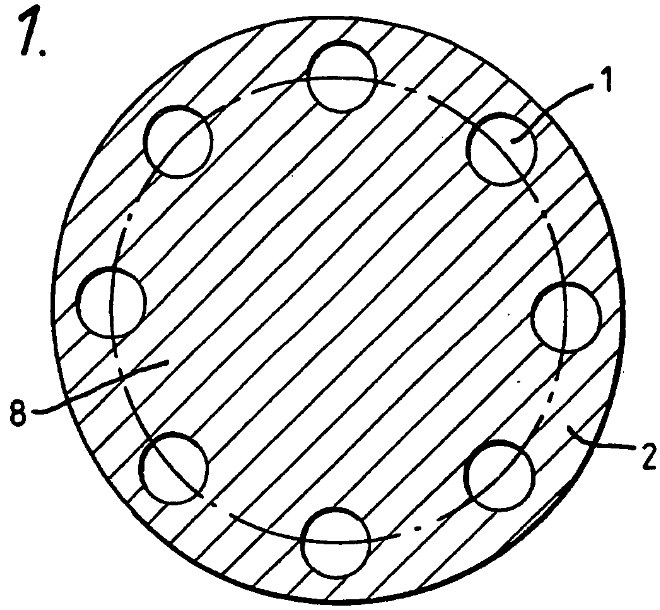


Fig. 2.

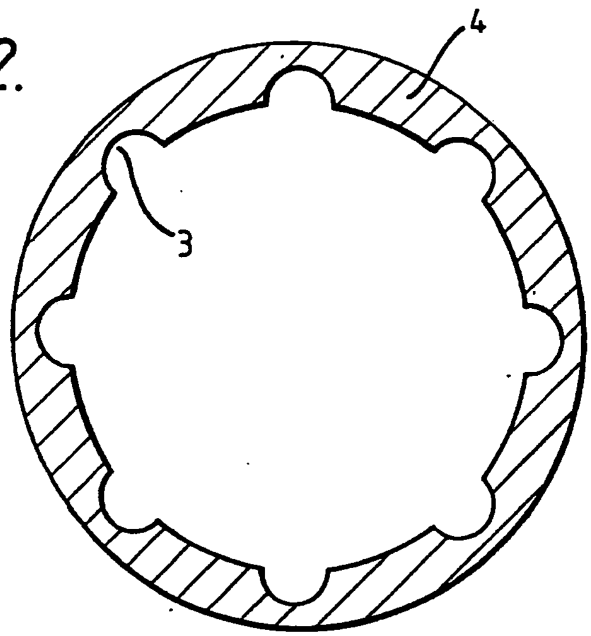


Fig. 3.

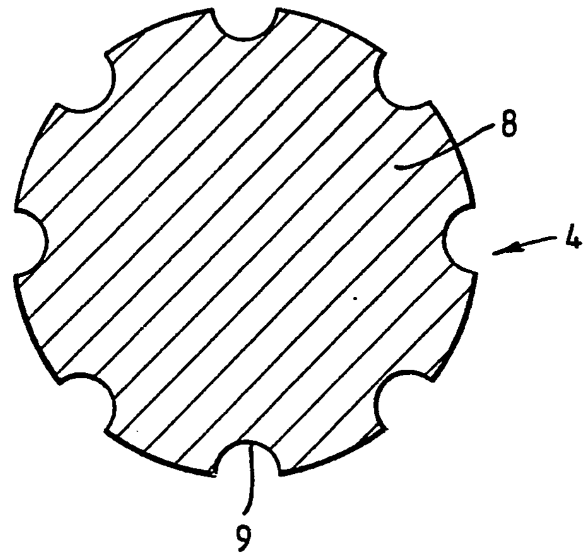
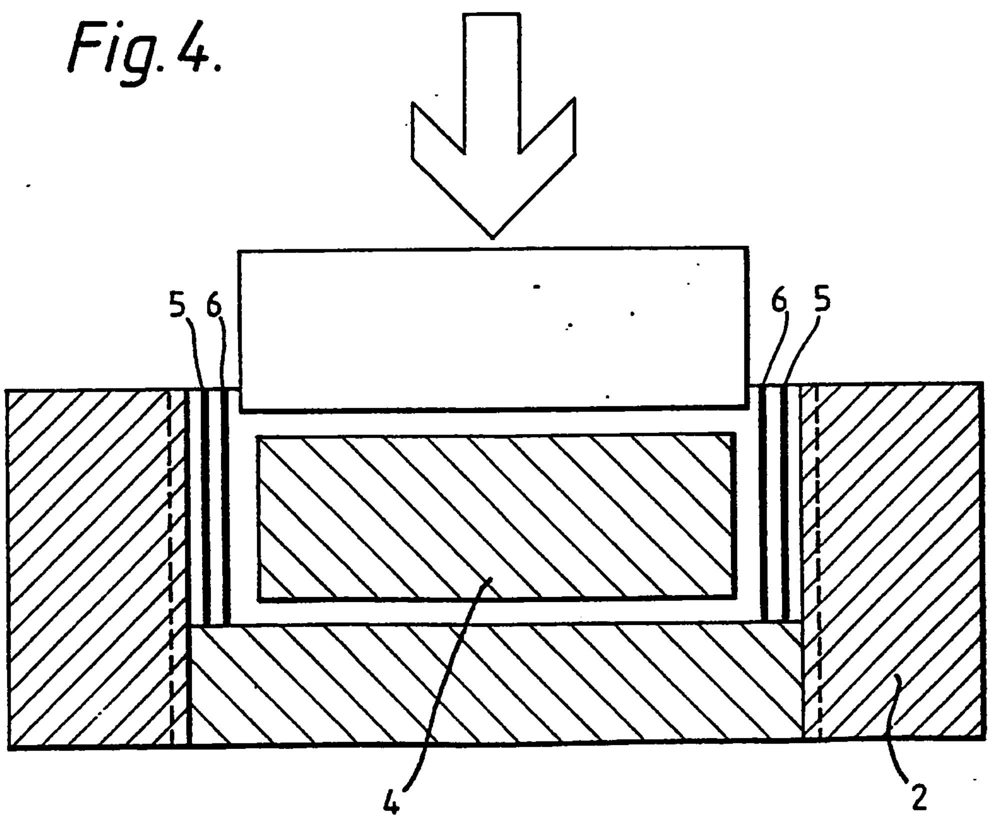


Fig. 4.



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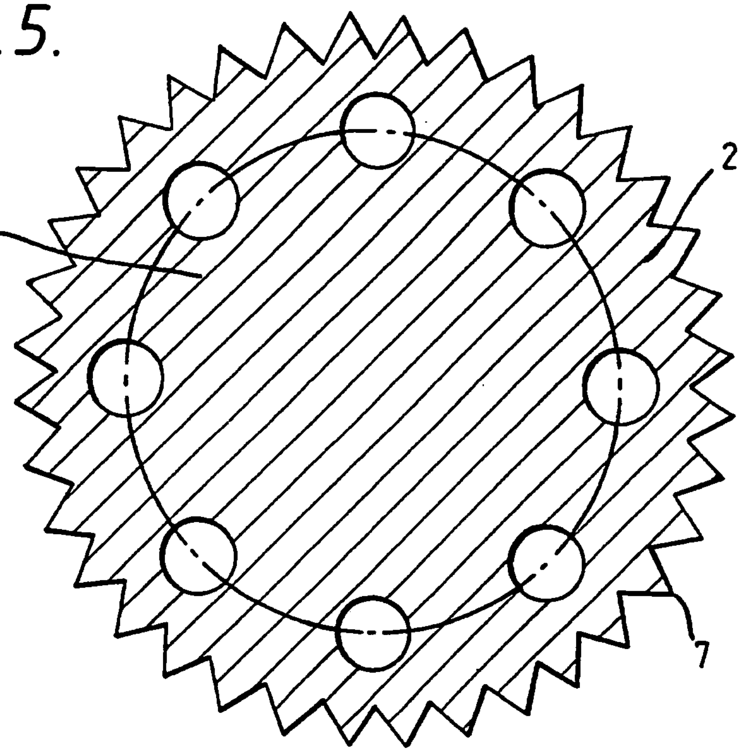


Fig. 6.

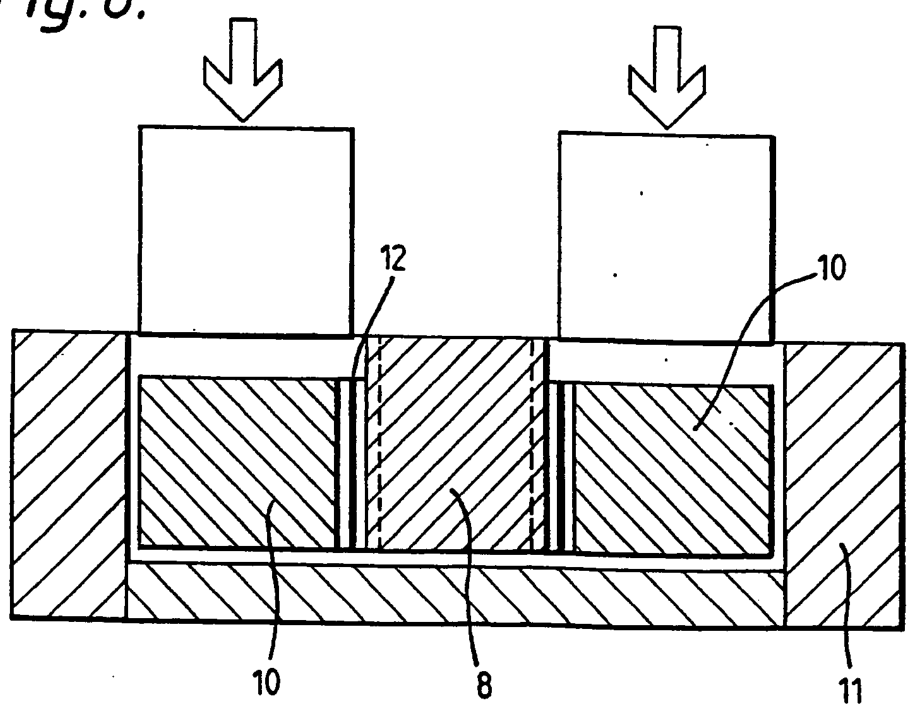


Fig. 7.

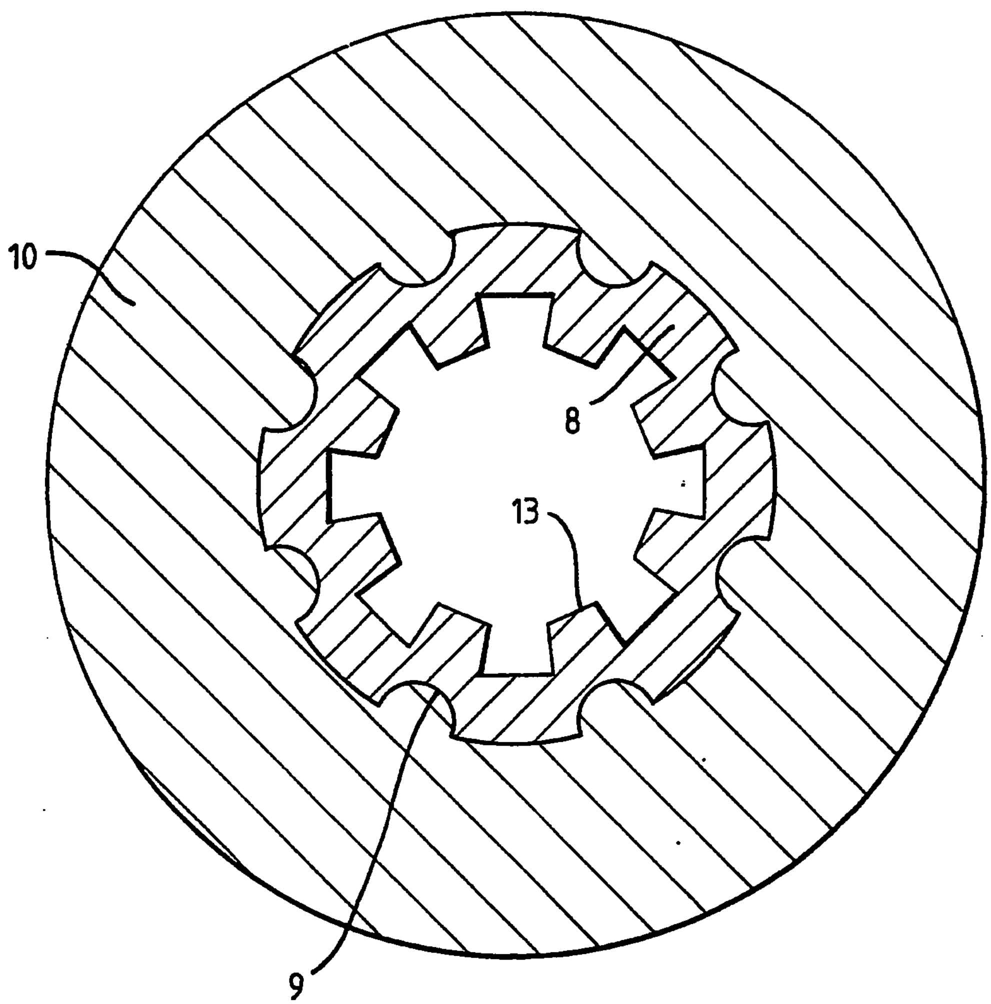
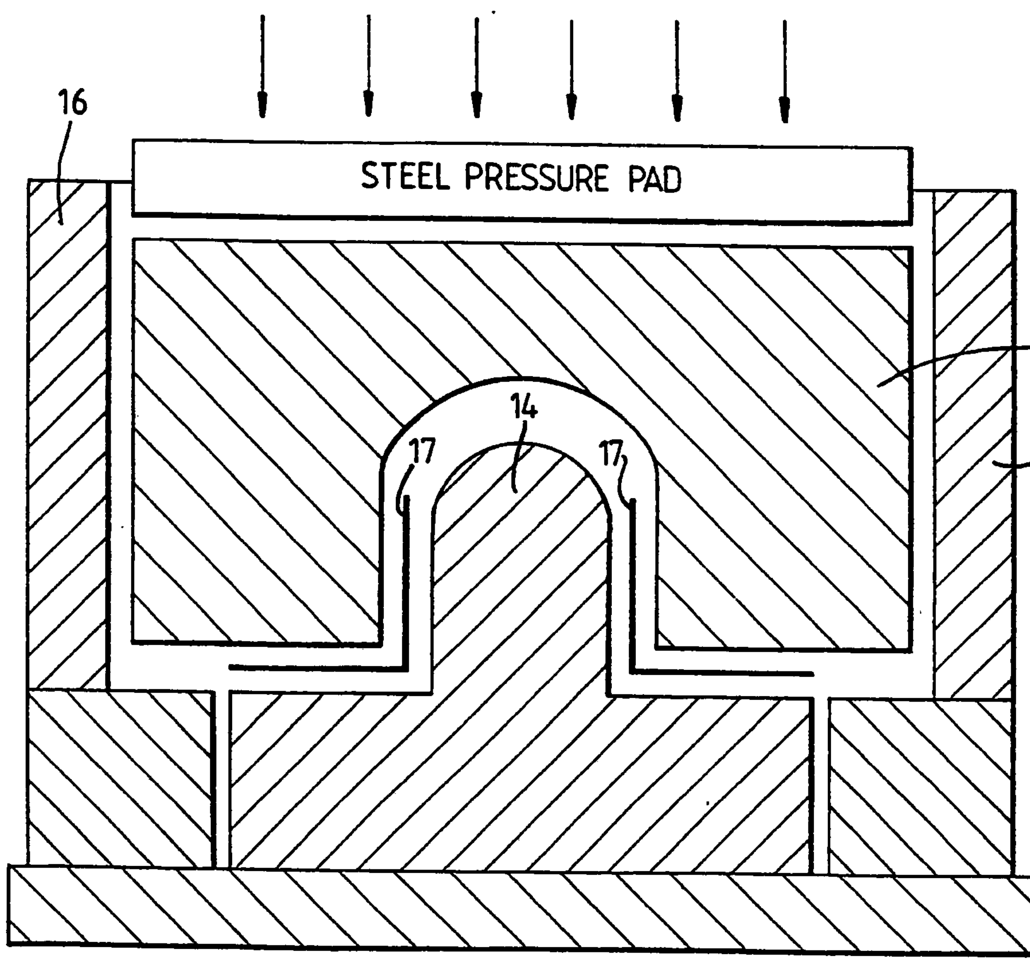


Fig. 8.



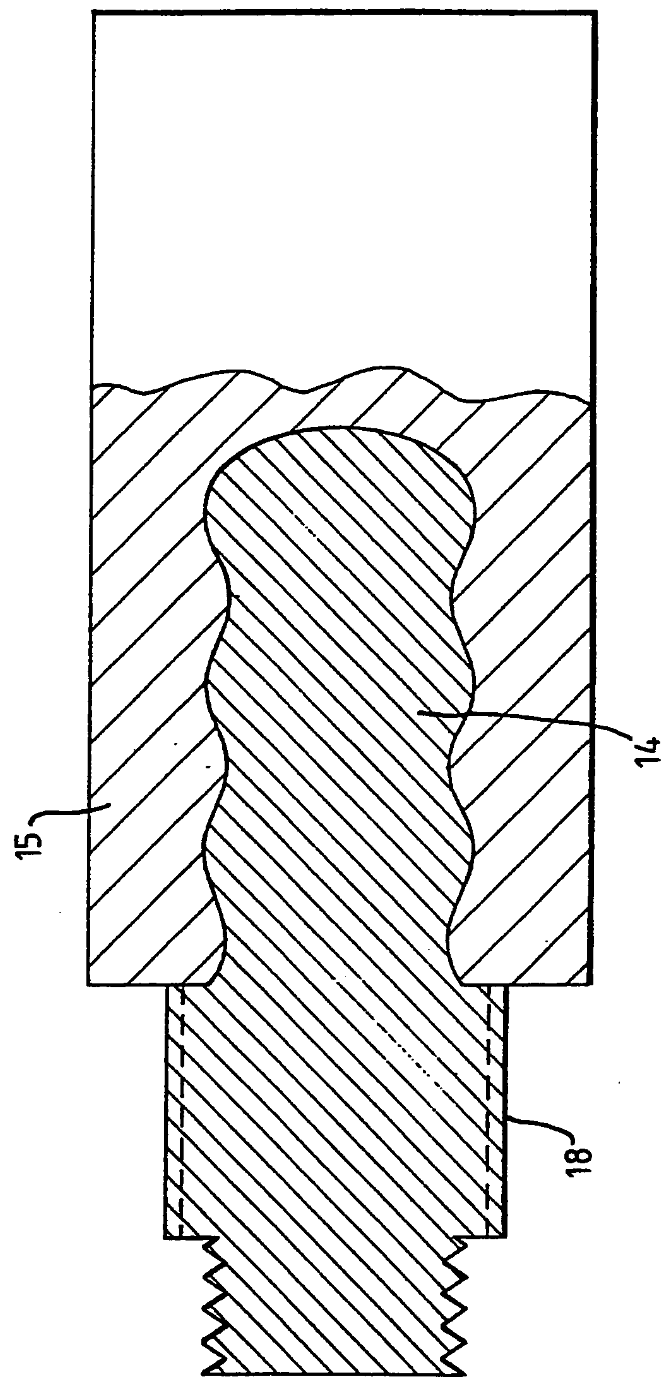


Fig. 9.

WEAR RESISTANT STEEL SURFACES ON ALUMINIUM, TITANIUM AND NICKEL-BASE ALLOYS

This invention relates to machinery components such as gears, bearing surfaces and splines having a load bearing portion of a hard wearing steel and another portion or portions of a non-ferrous metal such as a lightweight aluminium or titanium alloy, or a high temperature superalloy. The invention is principally but not exclusively directed to the field of power train parts for aerospace components.

In the aircraft industry weight savings are of obvious importance and gearing, especially ancillary gear boxes and on drive shafts in aircraft, might be a fruitful area to seek weight reductions. At present, heavily loaded gear train parts are manufactured in the main from conventional gear steels such as carburised and nitrided steels or flame/induction hardenable steels, and shafts and gears made of these materials represent an appreciable portion of the weight of the aircraft. Lighter materials such as aluminium alloys or titanium alloys are not in themselves suitable for the gear parts in question because they do not possess the required degree of resistance to wear when used in highly loaded applications.

Attempts have already been made to reduce the weight of helicopter rotor gears by utilizing a conventional gear steel rim in conjunction with a lightweight hub of material such as a titanium alloy with a bolted joint between the two metal parts. This approach is of limited application for it necessitates suitable sized and configured parts to accommodate the bolted

joint. Precautions must be taken to avoid fretting between the bolted surfaces.

There has also been work outside the helicopter field, directed towards improving the performance of lightweight alloys to a degree sufficient to enable these alloys to be utilized as gear materials for highly loaded applications through the provision of hard wear-resistant surfaces by surface treatment or coating. For titanium alloys nitriding and possibly other surface treatments have been tried, but reports indicate that these treatments have not been effective because they lead either to surface embrittlement or insufficient depth of elemental diffusion, by virtue of the fact that the concentration gradient across the surface necessary to obtain sufficient hardness by the diffused elements is also sufficient to create an embrittled layer at the surface. It has been reported that surface coating with nickel has been attempted but is also ineffective because it has been impossible to prevent flaking damage.

The object of this invention is to provide a composite machine part formed from two dissimilar metals more useful than those currently available having the principal aim of reducing the weight of aerospace gear trains. A subsidiary aim is however to enable composite gears to be formed to operate under conditions in which factors other than weight, eg high temperatures might dictate that part of the gear train is formed from a metal, such as a nickel based superalloy, that might not have properties suitable for forming the toothed part of the component.

The invention is a composite machinery component comprising two parts, one of these parts consisting of a hardenable steel and the other part of a non-ferrous metal, in which these two parts are integrally united at a joint configured such that the joint portion of one of the parts encircles an interprojecting portion of the other part, wherein the steel part has at least one keying recess or projection on

its interfacial surface and the non-ferrous part has been united with the steel part at the joint by plastically deforming it in situ to accommodate intimately the configuration of the steel part and has been welded thereto by a diffusion bond.

The non-ferrous part of the machinery component may be of aluminium or titanium or alloys based on these which are lightweight and readily deformable in for example the superplastic forming or isothermal forging regimes. The likely forming temperature, and indeed the diffusion bonding temperature are significantly above normal ambient and gearing operational temperatures. It follows that if the coefficients of thermal expansion of the metals are significantly different, thermal expansion and contraction must be taken in account in the design of the machinery component. It is desirable that the outermost part of the component exerts a compressive force on the innermost part at the joint at all temperatures below the diffusion bonding temperature and more particularly, at temperatures likely to be experienced by the component during storage or in use to avoid tensile forces across the diffusion bond from thermal effects. This imposes limits on the configurations of joint suitable for any pair of materials. When a titanium alloy or other material having a lower cofficient of thermal expansion than steel is used for the non-ferrous part then it should form the innermost of the two parts at the joint. This ensures that the innermost part of the joint is compressed by the outermost steel part at all temperatures below that at which the component was formed. If the non-ferrous part is of a material, such as aluminium or its alloys, having a coefficient of thermal expansion greater than steel then this part and not the steel should be outermost at the joint. This is of particular significance when using an aluminium/steel pairing because of the magnitude of the discrepancy in their expansion coefficients. Two typical components exemplifying the invention are a steel gear wheel

with a titanium alloy shaft and an aluminium alloy shaft with a steel core.

Adequate diffusion bonding technology using both solid and liquid phase methods already exists to achieve welds between steel and non-ferrous metals which will be sufficient for the purposes of this invention. A typical strength of a diffusion bonded joint would be 60% of the strength of the weakest metal. However with suitable configuration and dimensions the physical keying of the joint of this invention could have a strength in shear approaching that of the non-ferrous metal. In addition, in gear wheels for example, the joint interface can be positioned well away from the highly stressed regions such as gear teeth roots and this reduces the demands placed on joint strength.

The keying is preferably achieved by providing grooves in the interfacial surface of the non-ferrous metal. The grooves will be aligned so as to give strength in directions that experience the greatest stress. Axial grooves give the joint strength to withstand rotational shears, whilst circumferential grooves impart strength to withstand axial shears. It is therefore possible that both axial and rotational strength will be required necessitating both types of groove or an arrangement such as helical grooves that have a component in each direction.

The grooves are preferably semi-cylindrical in cross-section as the deforming metal readily takes this shape facilitating bonding at the interface.

When solid state diffusion bonding techniques are used to join the metals it is preferable that the non-ferrous metal is deformed slowly (ideally superplastically) and isothermally at constant pressure as this allows it to fill the grooves in the steel part at the interface more completely. It may however be quicker and therefore cheaper to hasten the deformation process and for joints that are not very heavily loaded or subject to fatigue loading this may be acceptable because there is not

such a stringent requirement for the deformed metal to completely fill the grooves.

For aluminium alloys, which tend to form a thick oxide film it may be desirable to coat the aluminium surface by conventional electroplating or vapour deposition techniques with a protective metal such as copper or silver which would greatly reduce the amount of oxide at the bond interface.

The invention will now be described by way of example with reference to figures 1-9 of the drawings of which:

figure 1 is a cross-section through a steel bar, with drilled holes,

figure 2 is a cross-section through the steel bar of figure 1 with its core bored out,

figure 3 is a cross-section through the steel bar of figure 1 with its rim removed,

figure 4 is a section through the apparatus used to join a steel gear wheel to a titanium shaft,

figure 5 is a section through a steel gear wheel formed using the apparatus of figure 4,

figure 6 is a section showing the apparatus used to join an aluminium alloy shaft to a steel core,

figure 7 is a section through an aluminium shaft with internal steel splines formed by the apparatus of figure 6,

figure 8 is a section showing the apparatus used to join an aluminium shaft to a steel core,

figure 9 is a longitudinal section through a component formed by the apparatus of figure 8.

The following examples illustrate methods that may be used to form a gearing component of this invention. Combinations of steel/titanium alloy, steel/aluminium alloy and steel/nickel alloy are included so that their particular problems can be appreciated and overcome.

EXAMPLE 1

Steel/Titanium alloy Combination

A 25mm length of gear steel is drilled and reamed as shown in figure 1. The holes 1 run axially through the length of the steel and are 3mm in diameter. They are positioned with the centre of the holes 10mm from the edge of the bar. The steel bar is then bored out to a diameter that intersects the holes to leave a 10mm rim 2 with hemispherical grooves 3 on its internal surface oriented parallel to the bar axis shown in figure 2. The orientation of the grooves gives in the finished component maximum resistance to shear in the joint about the bar axis.

The shaft is formed from a titanium alloy with composition Ti-6Al-4V. Figure 3 shows the shaft 4 inserted in the steel rim 2. Interlayer foils of copper 5 and vanadium 6 are placed between the steel rim 2 and the titanium alloy shaft 4. Figure shows the apparatus used for the subsequent vacuum hot forming of the component. Axial pressure of 20 MPa is applied in the direction indicated by the arrow for 1 hour at a temperature in the range between 880 and 900°C. Under these conditions the titanium alloy shaft 4 deforms superplastically and compresses the interlayers 5 and 6 into the steel rim 2 surface as shown in figure 4. When given sufficient time a solid state diffusion bond is subsequently formed.

The system is then allowed to cool to room temperature. As steel has a higher thermal expansion coefficient than titanium the steel rim contracts more than the titanium shaft and a joint in compression is formed. This adds greater strength to the diffusion bonded joint that is formed at the interface between the two metals. The joint strength could approach the shear strength of titanium.

EXAMPLE 2

Aluminium alloy/Steel combination

To form a suitable component from a pairing of steel and an aluminium alloy a similar process to that described in example 1 can be employed but to form a compressive joint the steel is used to form a core with internal gear teeth and the aluminium provides the outer encircling shaft. Similarly to example 1 a 25mm length of gear steel is drilled and reamed as shown in figure 1. The rim of the bar is then removed to a depth of 10mm leaving a central steel core 8 with hemispherical grooves 9 running axially along its surface as shown in figure 5.

An aluminium alloy shaft 10 is then placed around the steel core 8 as shown in figure 6. An interlayer of copper foil 11 is placed between the core 8 and the shaft 10. For aluminium alloy 8090 (Al-Li-Cu-Mg-Zr) the system is then heated to 460°C and a pressure of 25 MPa is applied in the direction shown by the arrow for 2 hours. An outer cover 12 surrounds the aluminium alloy shaft to prevent it being deformed on its outer as well as its inner face under the applied pressure. The aluminium alloy and interlayer deform to fill the grooves 9 in the steel core 8. The temperature is then raised to 560°C for ½ hour to enable a liquid phase diffusion bond to occur due to the formation of a low melting point eutectic phase between the aluminium and copper. The centre of the steel bar can then be bored out and steel splines 13 shown in figure 7 attached. Alternatively, the steel bar could be bored out and teeth cut in its inner surface so that they form an integral part of the steel core.

For RAE 72 alloy (Al-Cr-Fe) the system is heated to 400°C and a pressure of 225 MPa is applied to creep form the alloy for up to 4 hours. After contact a solid state diffusion bond is formed between the aluminium alloy and copper interlayer.

Again as the system returns to room temperature the outer element, this time the aluminium shaft, that has the higher thermal expansion coefficient, contracts to a greater extent than the central core and a diffusion bonded joint strengthened by compressive stresses is formed.

EXAMPLE 3

Steel/Aluminium alloy combination

Under some circumstances an outer steel gear wheel may be required. As the aluminium component must encircle the steel to prevent radial tensile stresses that would otherwise occur at the aluminium/steel interface during cooling after heating, the configuration must differ from that described in example 1.

To form a joint under compressive stresses for a steel gear wheel on an aluminium alloy shaft the steel bar of this example has the longitudinal cross-section 14 depicted in figure 8. The narrower section of the bar is similar to the steel bars used in examples 1 & 2. This section is drilled and reamed and the rim removed in the same manner as described in example 2. An aluminium alloy shaft 15 is placed around the grooved part of the steel bar and a copper interlayer 17 is placed between the bar 14 and shaft 15. A container 16 is again provided to prevent the aluminium being deformed in directions other than those intended when the axial pressure is applied. The system is heated and deformed by pressure in the direction given by the arrow. The temperature and pressure being the same as for example 2.

The resulting joint between the alloy shaft and the steel insert is in compression when the system returns to room temperture. The steel surface extending beyond the alloy shaft can then either be machined to produce gear teeth, splines or a bearing surface. Figure 9 shows the resulting component with the surface 18 with splines or a bearing surface.

EXAMPLE 4

Steel/Nickel alloy combination

Components formed from steel and nickel alloy Nimonic 75 can be made in the same way as those from titanium and steel. A 25mm length of gear steel is drilled and reamed and bored out in the same way as described in example 1. A nickel alloy shaft is inserted in the same way as the titanium shaft in example 1. Instead of copper and vanadium being used as in example 1 interlayers of copper and nickel or nickel alone are used. The system is isothermally forged at 925°C under an axial pressure of 100 MPa for 2 hours using apparatus similar to that disclosed in figure 3. Nickel and steel have relatively similar thermal expansion coefficients. As a result in the joint between nickel and steel the compressive stresses will be smaller than those between titanium and steel and aluminium and steel. The keying between the parts at their interface is not affected and will still have a room temperature shear strength approaching that of the shear strength of the nickel alloy.

The examples seek only to be representative of the ways in which the composite component of this invention can be formed. In particular other interlayers well known in the art of diffusion bonding can be substituted for those used in the specific examples.

CLAIMS

1. A composite machinery component comprising two parts, one of these parts consisting of a hardenable steel and the other part of a non-ferrous metal, in which these two parts are integrally united at a joint configured such that the joint portion of one of the parts encircles an interprojecting portion of the other part, wherein the steel part has at least one keying recess or projection on its interfacial surface and the non-ferrous part has been united with the steel part at the joint by plastically deforming it in situ to accommodate intimately the configuration of the steel part and has been welded thereto by a diffusion bond.

2. A composite machinery part as claimed in claim 1 wherein the keying recesses are axial grooves.

3. A composite machinery part as claimed in claims 1 or 2 wherein the keying recesses are helical grooves.

4. A composite machinery part as claimed in claim 2 or 3 wherein the grooves are hemispherical in cross-section.

5. A composite machinery part as claimed in any one of claims 1-4 wherein the plastic deformation of the non-ferrous metal is by an isothermal forging process.

6. A composite machinery part as claimed in claim 1 wherein the non-ferrous metal is a titanium alloy, substantially as hereinbefore described with reference to figures 1-4 of the drawings.

7. A composite machinery part as claimed in claim 1 wherein the non-ferrous metal is an aluminium alloy, substantially as hereinbefore described with reference to figure 1 and figures 5-9 of the drawings.

8. A composite machinery part as claimed in claim 1 wherein the non-ferrous metal is a nickel alloy, substantially as hereinbefore described with reference to figures 1-4 of the drawings.

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